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EFFECT OF HEAT STRESS AND PROLONGED ACTIVITY ON PERCEPTUAL-MOTOR PERFORMANCE

by Raymond E. Reilly and James F. Parker, Jr.

Prepared by
BIOTECHNOLOGY, INC.
Arlington, Va.
for

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FOREWORD

This report was prepared by BioTechnology, Inc., as one task under Contract No. NASW-1329 with the National Aeronautics and Space Administration. This work was performed under the direction of the Manned-Systems Integration Branch, Biotechnology and Human Research Division, of the Office of Advanced Research and Technology, with Dr. Stanley Deutsch serving as the NASA Project Monitor. Dr. Deutsch made a number of useful suggestions during the formulation of the experimental design and was most helpful during the review of the draft manuscript.

ABSTRACT

This study was concerned with the assessment of the effects of two stress conditions on 16 basic dimensions of perceptual-motor performance. Subjects were tested under conditions of heat stress (86° F effective temperature for a period of six hours) and prolonged activity (24-hour continuous activity, with two 2-hour rest periods). In general, perceptual-motor performance levels were well maintained under these stress conditions. Under heat stress, six tests showed facilitation, while two showed degradation of performance. Facilitation under heat stress was accounted for in terms of arousal theory under which activities requiring minimal information processing and involving simple motor reactions appear to benefit from the alerting component of arousal. Under prolonged activity, two tasks showed facilitation and one showed degradation in performance. These effects were explained in terms of requirements specific to the individual tasks. In general, there was essentially no change in performance effectiveness during the 24-hour period of prolonged activity.

Under heat stress, oral temperature and pulse rate increased significantly, lending support to the inference of increased arousal. Under prolonged activity, no change was noted in oral temperature, pulse rate, or blood pressure. This was consistent with the general lack of change in the performance measures indicating this level of stress was well tolerated.

To an extent compatible with the intensity of the stress conditions which were used, the basic dimensions of perceptual-motor performance appear differentially sensitive to stress. The results offer insight as to the mechanisms whereby stresses such as were used in this study affect more complex operational performance. The findings of this investigation demonstrate the usefulness of the integrated measurement system as a device for the study of human performance.

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INTRODUCTION

Man is constituted to function within a highly restricted physical environment characterized generally by the natural conditions obtaining in temperate regions of the Earth's surface. With minor variations in ambient conditions, man's homeostatic mechanisms serve to control the effects upon the body. When demands of the environment exceed the limits of physiological regulatory systems for extended periods, deterioration and death occur unless external support is obtained.

For many reasons, man has sought to expand his operating environment, increase his productivity, and achieve an understanding of the universe. To these ends, he has developed machines and systems to increase the range and capacity of his senses and physical performance. Owing to technological obstacles and costs in providing the human operator with an optimal work environment under all circumstances, he is often required to perform under physical conditions which tax or exceed his physiological capacity. Such is the domain of research on human stress, a primary objective of which is to specify the time-intensity functions which signify the limits for maintenance of performance, comfor and tolerance. Through such research, a parallel goal is pursued of understanding the nature and function of the human organism in interaction with his environment.

Stress and Performance in the Aerospace Environment

Space beyond the Earth's atmosphere fails to meet any of the basic requirements for sustaining human life. Merely to survive, man must be encapsulated in a vehicle or garment which provides a breathable atmosphere, maintains pressure and temperature within prescribed limits, and shields against ionizing radiation. In order to enter and return from this environment, the human must endure severe and immobilizing acceleration forces in addition to other physical and psychological stresses.

Despite all of this, man's role in space has been established and continues to expand. A great deal is already known concerning means of maintaining proper physiological functioning within the space environment. Considerably less is known about man's performance capabilities in space and the manner in which these capabilities might be altered during extended missions. However, a great deal is expected of the human operator during space flight. This was evident five years ago, even before the highly successful series of Gemini flights, as shown in the following description of the human's role during space activities (Chambers, 1962):

> The current concept of man in space regards him primarily as a scientific observer and flight systems monitor, with added responsibility and capability for providing backup reliability to the space capsule system in the event of a malfunction of system components. Thus, man is a scientific specimen, an observer and monitor, an information processing unit and decision maker, a flight controller and a functioning component of the space vehicle....The consensus is that man's best role is as a flight control element in addition to those associated with curiosity, scientific observation, systems monitoring and decision making.

Need for Improved Performance Measurement Techniques

As excursions into space become more frequent and prolonged, the need increases for information concerning man's capability not only to survive, but to perform optimally for extended periods as well. Such information bears directly upon the design of systems upon which the human depends for sustenance and protection as well as those underlying important scientific missions. Further, with the advent of large orbiting space stations and laboratories, many aspects of human performance will be called into play beyond those required for control of the space vehicle and its life support systems.

Engineering and cost considerations make the use of conventional laboratory apparatus and procedures unsuitable for the study of human performance in space. Size and weight limitations of equipment and attendant problems of test administration, scoring, and data storage are some of the obstacles which require development of new devices and measurement techniques.

Unlike the assessment of biological functioning, measurement of perceptual-motor performance requires active participation by the subject. At present, astronauts have little time available for such activities This, in turn, demands that performance testing be accomplished quickly and efficiently.

Development of Integrated Perceptual-Motor Performance Test Battery

Under the auspices of the NASA Manned Spacecraft Center, work was begun in 1964 to develop an integrated test battery to measure the primary dimensions of human perceptual-motor performance. An extensive review and analysis of the technical literature on perceptual-motor performance was conducted giving primary attention to factor-analytic investigations. A list of relatively independent and basic measures of performance were identified. From these, eighteen were selected for inclusion in the battery. Selection was in part based upon correspondence of the measures to the kinds of activities required of astronauts in the Gemini missions. The standard tests chosen then were modified to permit their incorporation into a unified measurement console whereby each test could be self-administered. Table 1 lists the eighteen tests incorporated into the measurement console and describes the performance required by each test, the duration, and the score obtained. The research leading to the development of this console and the resulting prototype test system are fully described elsewhere (Parker, Reilly, Dillon, Andrews, & Fleishman, 1965).

Utilizing the concepts of the initial study, the measurement system was redesigned to permit remote test administration and to provide a reliable and easily maintained instrument suitable for extended use as a research device. This was accomplished as the first phase of the present effort and is described in a separate report dealing with the development aspects of the improved system (Reilly & Parker, 1967).

Table 1

Description of Tests, Performance Required, and Score Obtained

Test	Performance required	Test Duration	Score
Arm-hand Steadiness	Hold tip of stylus in aperture with arm and hand fully extended.	Three 10-second trials equally spaced over one minute.	Total contacts with rim in three 10-second periods.
Wrist-finger Speed	Tap back and forth between two switches.	Three 10-second trials equally spaced over one minute.	Total taps accumulated in three 10-second periods.
Finger Dexterity	Assemble and disassemble small threaded units; attach and retrieve from board in prescribed sequence.	About 60 seconds.	Time to complete test sequence.
Manual Dexterity	Insert and retrieve block from shape coded receptacles in prescribed sequence using one hand.	About 60 seconds.	Time to complete test sequence.
Position Estimation	Use stylus to contact prescribed target making arm-hand movement without use of vision.	About 60 seconds for a 10-target sequence.	Each trial scored as 0, 1, 2, or 3. Maximum= 30 points for 10 targets.
Response Orientation	Move lever-switch in appropriate direction corresponding to each of four colored light stimuli.	2 minutes	Cumulated response time to sequence of 24 signals.

(Continued)

Table 1--Continued

Test	Performance required	Test Duration	Score
Control Precision	One-hand, 2-axis pursuit tracking task with circular target course and position dynamics.	1 minute	Time integral of absolute error voltage.
Speed-of-Arm Movement	Move hand between switches 24 inches apart.	About 30 seconds for 5 trials.	Mean movement time based on 5 trials.
Multilimb Coordination	Two hand, 2-axis compensatory tracking task with rate control dynamics. Left hand controls Y-axis; right hand controls X-axis.	1 minute	Time integral of absolute error voltage.
Position Reproduction	Use stylus to contact prescribed target; motion is made first with vision, then repeated without vision for score.	About 30 seconds for a 10-target sequence.	Each trial scored as 0, 1, 2, or 3. Maximum= 30 points for 10 targets.
Movement Analysis	Adjust knob to null acceleration in CRT target dot. (i.e., set dot to constant velocity.)	About 10 minutes for 5 initial conditions.	Absolute value of adjustment error. Convertible to angular acceleration error.
Movement Prediction	Predict when CRT target dot arrives at prescribed position. Target is viewed in motion and then disappears before reaching reference point.	About 10 minutes for 3 trials on each of 5 target velocities.	Absolute error voltage corresponding to CRT dot position error.

(Continued)

Table 1--Continued

Test	Performance required	Test Duration	Score
Rate Control	One hand, 2-axis compensatory tracking task with first order dynamics.	1 minute	Time integral of absolute error voltage.
Acceleration Control	One hand, 2-axis compensatory tracking task with second order dynamics.	1 minute	Time integral of absolute error voltage.
Perceptual Speed	Judge pairs of meter indications as same or different.	About 30 seconds	Time to complete sequence of 24 presentations and number of errors made.
Time Sharing	Monitor two meters to detect random onset of pointer movement. Separation of meters prevents simultaneous viewing.	4 minutes	Accumulated response time for 24 events.
Reaction Time	Press switch in response to tone (auditory reaction time) or light (visual reaction time).	Either modality--four trials spaced over one minute.	Mean reaction time based on four trials.
Mirror Tracing	Trace maze with stylus using mirror mounted in visor.	About 1 - 5 minutes.	Time to complete maze and number of contacts made by moving off path.

PROCEDURES

Eighteen subjects were exposed to six hours' heat stress and a twenty-four hour work-rest program on different days and in counterbalanced order. Perceptual-motor performance measures on sixteen tasks and physiological data were obtained during stress and in pre- and poststress sessions.

Independent Variables

Heat Stress

Unacclimatized male subjects were exposed to 100°F dry-bulb, 80°F wet-bulb temperatures (effective temperature: 86°F) for a period of six hours. Subjects were stripped to the waist and wore only cotton slacks (chinos), socks, and street shoes. During heat exposure they remained seated at a table and performed paper-and-pencil tests except for the final 90 minutes which were devoted to testing on the perceptual-motor measurement console. Subjects were permitted drinking water *ad libitum* throughout the six hours except for periods 15 minutes prior to obtaining physiological measurements. A complete listing of the activities of subjects during the period of heat stress is presented in Appendix A.

Prolonged Activity

Subjects were restricted to an experimental cubicle (described below) for 24 hours except for use of an adjacent lavatory. The first and final 90 minute periods of the 24-hour session were devoted to testing on the perceptual-motor performance console. The intervening time was spent on a prearranged program of sedentary information-processing and monitoring tasks. The subject work schedule and activities are presented in Appendix B. This work schedule was pre-recorded on tape and designed to elicit continued performance by the subject. All activities were presented as "tests" which ostensibly would be scored for speed and/or accuracy as part of the experiment. Every effort was made to avoid prolonged monotonous or repetitive tasks which would have required low levels of attention or caused the subjects to become bored or disinterested.

Each experimental session began at 0800 and terminated at 0800 the following morning. Subjects were given a 30 minute break for lunch (1200-1230) and two subsequent two-hour rest periods, 1700-1900 (including dinner) and 0100-0300. Subjects' watches were removed and they were not advised of the time during the 24 hour session.

Ambient temperature during prolonged activity sessions was in the range 70 to 78°F. Relative humidity varied between 30 and 50 percent.

Dependent Variables

Perceptual-Motor Performance Tests

Sixteen tests provided by the console were administered to each subject in accordance with the experimental design described later. The performance required in each test and the type of score obtained are listed in Table 1.

Physiological Measures

Oral temperature, pulse rate and blood pressure measurements were obtained upon the subject's arrival and at two-hour intervals throughout all phases of the experiment, including practice sessions conducted prior to the introduction of the stress conditions.

Oral temperature was obtained with a clinical mercury-in-glass thermometer placed under the tongue. In order to increase the reliability of this measure the following procedure was strictly followed: The subject was required to keep his mouth closed for 15 minutes prior to temperature measurement. The thermometer was inserted under the tongue for a period of no less than five minutes.

Blood pressure was obtained with a sphygmomanometer, with the cuff applied to the left arm. Pulse rate was measured by palpation of the radial artery at the left wrist for a period of 30 seconds. Subjects remained seated while the above measures were taken.

Personality Measures

Two psychological tests, the Minnesota Multiphasic Personality Inventory (MMPI) and the Edwards Personal Preference Schedule (EPPS) were completed by each subject during the first two hours of the work/rest schedule. These tests were intended to provide information concerning any personality characteristics which might affect the influence of environmental stress or otherwise contaminate the experimental results.

Subjects

Eighteen males ranging from 18 to 48 years of age served as subjects. These men were professional firemen. All were in apparent good health and physical condition and had passed a physical examination within the past six months as required by their occupation.

Subjects were paid for their services.

Apparatus

Experimental Cubicle

The experimental cubicle was approximately eight feet in length, width and height. The experimenter viewed the subject through a 24 x 24 inch window which was covered by a blackout curtain when not in use.

Environmental Control Equipment

Temperature of the experimental cubicle was maintained by thermostatically controlled radiant heaters; humidity was controlled by an evaporative humidifier.

Temperature and humidity were monitored by use of a whirling hygrometer. Dry bulb temperature during heat stress was quite stable ranging from $98^{\circ}F$ to $102^{\circ}F$. Wet-bulb temperature increased slowly during the six hours from $76^{\circ}F$ at the start to $84^{\circ}F$ by the end of the session. This was presumably due to evaporation of perspiration within the experimental cubicle.

Perceptual-Motor Performance Console

The perceptual-motor performance device is shown in Figure 1. A detailed description of its operation and task requirements is reported separately (Reilly & Parker, 1967). The eighteen tests provided by the console are listed in Table 1. Results for only sixteen tests were analyzed in this study. Data for Acceleration Control were eliminated because of the extensive learning period involved in this task. Data for Movement Analysis was discarded because of a suspected calibration error.

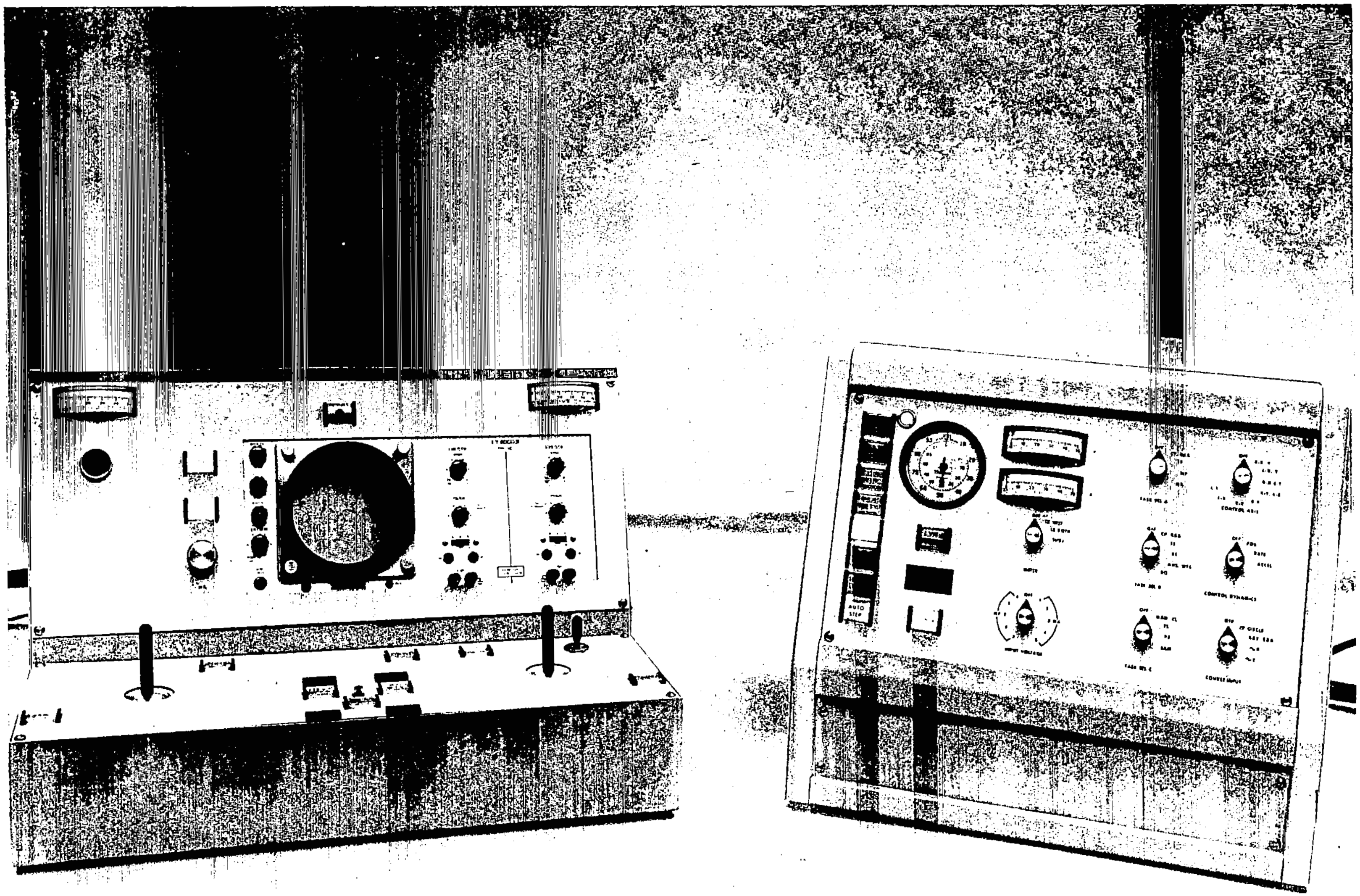


Figure 1. Improved Perceptual-Motor Performance Measurement System
Subject Console (left); Experimenter Console (right).

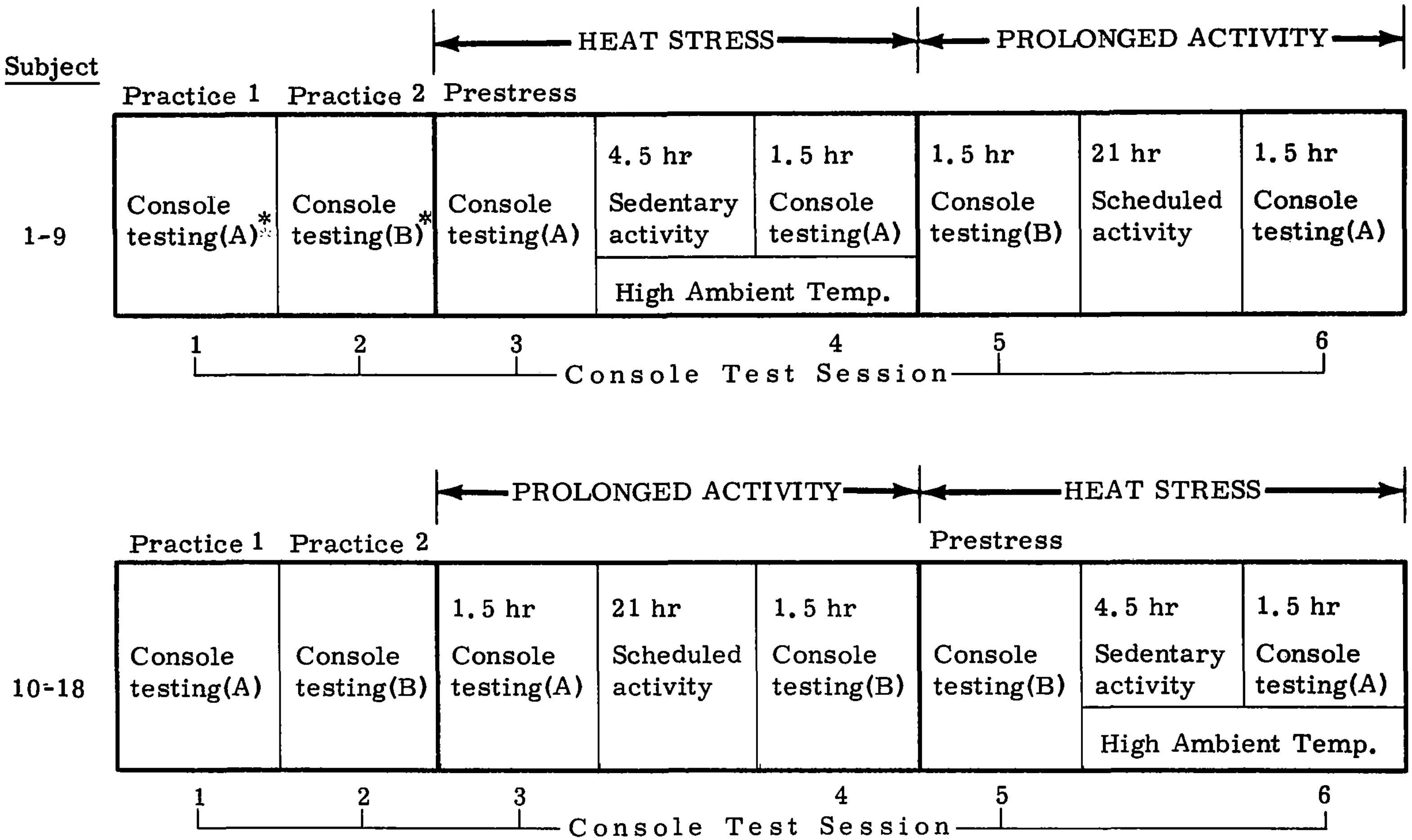
Experimental Design and Procedure

The arrangement of subjects and experimental conditions is shown in Figure 2. Subjects were run individually. A total of 18 subjects were given two practice sessions of two hours each on the console on separate days. The subjects were then divided at random into two groups corresponding to two orders of presentation of stress conditions. One group received heat-stress first, followed on a later day by prolonged activity condition; the second group received the prolonged activity condition first and then returned for the heat-stress. No subject received the stress conditions on successive days. The time interval between conditions ranged from three to seven days as determined by the subject's availability for participation in the experiment.

Each subject received an additional practice session on the console immediately preceding each stress condition, giving a total of four sessions under ambient conditions and two sessions under stress (one during the final 90 minutes of heat exposure and one during the final 90 minutes of the 24-hour work/rest period).

As noted above, approximately 90 minutes was required for a subject to complete the series of 16 tests. In order to reduce possible fatigue effects due to performing on the console for this length of time, two orders of test presentation were used. Because of the relatively large number of tests, complete permutation was not feasible. The 18 tests were therefore divided into two sequences (A, B) of nine each. Table 2 presents the specific tests contained in each of the two sequences. The two sequences were presented in counterbalanced order across subjects and experimental sessions as shown in Figure 2.

Subjects were not given the results of their performance at any time during the experiment.



* A, B indicates test administration sequence as shown in Table

Figure 2. Experimental design for administration of two stress conditions.

Table 2

Test Administration Sequences

Sequence A = Tests 1 - 18

Sequence B = Tests 10 - 18, 1 - 9.

1. Arm-hand Steadiness	10. Wrist-finger Speed
2. Manual Dexterity	11. Finger Dexterity
3. Position Estimation	12. Position Reproduction
4. Control Precision	13. Multilimb Coordination
5. Response Orientation	14. Speed-of-Arm Movement
6. Movement Prediction	15. Movement Analysis
7. Acceleration Control	16. Rate Control
8. Perceptual Speed	17. Time Sharing
9. Reaction Time (Vis. & Aud.)	18. Mirror Tracing

OBJECTIVES OF EXPERIMENT

The present experiment was conducted as the second phase of a two-part project. As noted above, the first phase was concerned with development of an improved perceptual-motor performance measurement system.

The objective of the research phase was to utilize the system to assess the separate effects of high ambient temperature and prolonged activity on perceptual-motor performance and the physiological indices of heart rate, blood pressure, and oral temperature.

The Nature of Stress Experiments

In comparing stress vs. nonstress performance on a given task, only three outcomes are possible: (1) improvement, (2) decrement, or (3) no change. Results are usually predicted or explained on the basis of interaction among three sets of factors: (1) the nature of the task, (2) environmental conditions, and (3) the state of the (subject) organism. Each of these factors is considered in the light of the other two in attempting to assess its relative influence on performance. For present purposes, we shall be concerned primarily with studies involving heat stress, sleep deprivation, and to some extent, those dealing with vigilance and information processing under environmental stress.

Task Considerations

Regarding sleep deprivation, Wilkinson (1964) comments: A task will be vulnerable (1) as it is complex, and (2) as it is lacking in interest, incentive, and reward. Of these factors, that of incentive may be the more influential, so that a highly complex task may be little affected by sleep deprivation if it is complex in an interesting and rewarding way.

Of many possible incentives, providing subjects with knowledge of results appears to have a highly rewarding influence (Wilkinson, 1961; 1963; Chapanis, 1964). The degree of involvement between subject and task would also appear to contribute to reducing the effects of sleep loss or boredom. Adams and Chiles (1960) speculate on the basis of their research on work-rest cycles that performance levels are more likely to be maintained on "active" tasks where subjects are required to perform temporally defined sets of actions than in "passive" tasks where the subjects sits and waits for something to happen with no way or predicting when an action on his part will be required.

Environmental Conditions

The forces of environmental stress may act mechanically upon a task to distort critical stimuli (e.g., effect of vibration on visual displays) or upon receptors or effectors (e.g., effect of acceleration on vision and body movements). It may exert influence less directly by providing a barrage of stimuli which compete for the subject's channels of information acquisition or disrupt attention and cognitive processes.

Depending upon the type and intensity of stress, it may serve to maintain a state of alertness in the subject at the one extreme or cause severe physiological collapse at the other. Environmental stress in conjunction with the mental and physical condition of the subject determines to a large extent his momentary ability to perceive and respond in performing a required task.

State of the Organism

The state of the human organism can be described in terms of the intensity of physiological functioning on a continuum ranging from sleep to wakefulness, where the waking state may be characterized by varying degrees of arousal, alertness, and energy mobilization (Freeman, 1940;

Lindsley, 1951; Hebb, 1955; Duffy, 1957). Kleitman (1939) has asserted that sleep is dependent upon reduction in afferent inputs to the waking center of the hypothalamus from various somatic and proprioceptive receptors, particularly the visceral receptors.

Numerous studies have drawn upon the concept of "level of arousal" in predicting and explaining the effect of stress on human performance. For example, Zuidema, Cohen, Silverman, and Riley (1956) in studying tolerance to prolonged acceleration have schematized a gradation of state from sleep to panic associated with activity of the autonomic nervous system. Fox, Goldsmith, Hampton, and Wilkinson (1963) hypothesized and confirmed that increased body temperature (102° F) would produce a state of arousal which in turn would lead to reliable improvement in performance on an auditory vigilance task.

Complementary results were obtained by Poulton and Kerslake (1965) who found simultaneous performance on two tasks (visual monitoring and auditory monitoring) to be maintained better during initial exposure to a warm, stimulating environment (113° F) than after entry to a less stimulating environment (77° F). Considering their own work together with that of Wilkinson, et al. (1963), they suggest a sequence of changes which occurs upon entering a hot environment. First, the initial stimulation from warmth on the skin, with corresponding fall in rectal temperature (overcompensation), produces an increase in the level of arousal. Next, as the temperature receptors of the skin adapt to the thermal stimulation and the rectal temperature rises, the level of arousal falls below normal. This gives the typical picture summarized by Pepler (1963) of the man who is inefficient in heat. Then, as the body temperature rises still further, the man becomes uncomfortably hot. This raises his level of arousal above normal again, as described by Wilkinson, et al. (1964). Finally, all performances deteriorate as the man begins to collapse from heat (Pepler, 1963). Poulton and Kerslake note further that performance of tasks which are affected by man's level of arousal may thus improve or deteriorate in a hot environment depending upon when performance is measured in relation to the sequence of changes.

Stennet (1957), following the theoretical formulations of Hebb (1955) and Freeman (1940; 1948), tested the hypothesis of an inverted-U relationship between level of arousal and level of performance. Subjects performed an auditory tracking task under different incentive conditions while measures of arm muscle potentials, palmar conductance and tracking control grip-strength were obtained as indications of "level of arousal." The results were interpreted as generally supportive of the hypothesis although the specific form of the inverted-U relationship could not be determined.

A further consideration regarding the interaction of environmental stress, level of arousal, and performance concerns the process of human information transmission. The problem is stated concisely by Carlson (1961) who notes that two approaches to the evaluation of man's reaction to his environment have developed: (1) the study of environmental stress and resulting physiologic strain, and (2) the study of stimulus-response patterns by means of psychologic techniques. Both changes in temperature (for example) and changes in the psychologic "stimulus" are inputs and in interacting may share subsystems or channels. If this is the case, these inputs would sum toward information overload or, at minimal inputs, toward the arousal or alerting of the system.

In testing this hypothesis by having subjects perform a visual vigilance task with varying information input rates and under different ambient temperatures Carlson found that when information input was low (i.e., 2 bits/sec), performance either did not change or was better at the higher temperatures. With the high input rate (8 bits/sec), however, errors increased at the higher temperatures.

Perceptual-Motor Performance Under Stress

From the foregoing discussion, which only hints at the complexity of the problem of accounting for the effects of stress on performance, it is clear that a host of factors must be considered if one wishes to predict the direction and magnitude of stress-induced changes. While after-the-fact explanations of performance variations are readily generated and quite credible, it is another matter to identify, quantify, and interrelate beforehand the pertinent aspects of the task, environment, and state of the organism. However, current theories of human performance and available psychophysiological data do provide some basis for making rather gross predictions concerning perceptual-motor performance under stress conditions such as were used in this study.

It may be assumed a heat stress condition will produce moderate to high levels of arousal, which will either facilitate performance through its "alerting" or "motivating" functions or will reduce efficiency through distraction of information overloading, depending upon the task involved. The intensity of the heat stress also must be taken into account. There is evidence, cited earlier, that slight to moderate levels of heat will increase arousal. However, as the heat is increased toward human tolerance limits, the facilitating effects of arousal are lost and performance rapidly deteriorates as the point of incapacitation is approached.

Prolonged activity is assumed to reduce level of arousal below normal (Corcoran, 1964) and hence, should not facilitate performance. Reduced alertness and lowered intensity of bodily functioning, however, would be expected to produce performance decrement to the extent that such is not counteracted by increased effort (via interest, motivation) of subjects.

The study described here was exploratory in nature and was designed primarily to validate the usefulness of the integrated measurement system as a research device for the study of human performance. However, reasonable intensities of the stress conditions were used in an attempt both to assess the general effect of this type of stress on performance and to determine the differential sensitivity of a number of basic dimensions of perceptual-motor performance to these stress conditions.

RESULTS

Perceptual-motor performance scores and psychological data were obtained under four non-stress (practice) and two stress (heat; prolonged activity) conditions. Data of two perceptual-motor tasks were discarded. Movement analysis was discarded because of suspected error in equipment calibration. Acceleration control was eliminated because of the extensive learning period required to achieve stable performance levels.

Preliminary Analysis

The data of each subject were examined to determine whether particular individuals exhibited a consistent pattern of performance change in response to either stress condition, whether this was accompanied by changes in the physiological measures, and whether any aspects of the personality inventories (MMPI; EPPS) showed marked deviations from the norm. The results of this analysis were negative, i.e., subjects showing obvious performance decrement under stress on particular tests maintained or improved their performance on other tests; individual subjects showing the greatest change in physiological measures did not exhibit marked or consistent changes in perceptual-motor performance.

Individual personality profiles obtained with the MMPI and EPPS were all essentially normal.

Perceptual-Motor Performance Analysis of Data

Means and standard deviations of performance scores for each test and experimental conditions based on the eighteen subjects are presented in Table 3.

Table 3

Means and Standard Deviations of Test Scores by Experimental Conditions

Condition / Test		Practice	Practice	Prestress	Prolonged Activity Stress	Prestress	Heat Stress	Units
Fine Manipulative Ability								
Arm-Hand	$\bar{x}$	29.4	21.1	22.0	12.8	15.1	16.8	Contacts (a)
Steadiness	S.D.	16.1	11.4	11.5	7.02	10.4	9.27	
Wrist-Finger	$\bar{x}$	120	128	130	131	128	137	Taps
Speed	S.D.	19.1	15.9	19.1	17.6	15.7	19.0	
Finger	$\bar{x}$	68.0	61.4	57.2	56.3	57.1	54.5	Seconds
Dexterity	S.D.	10.4	12.2	8.83	8.72	8.66	7.88	
Manual	$\bar{x}$	55.2	52.1	46.3	48.5	46.6	44.6	Seconds
Dexterity	S.D.	9.10	7.68	5.74	6.93	7.42	7.21	
Gross Positioning and Movement Ability								
Position	$\bar{x}$	14.4	14.7	16.4	16.5	16.1	15.1	Points
Estimation	S.D.	3.22	4.03	2.52	2.70	3.29	2.89	
Response	$\bar{x}$	14.2	13.1	12.5	12.4	12.6	11.4	Seconds
Orientation	S.D.	3.24	2.88	2.29	2.40	2.91	1.58	
Control	$\bar{x}$	35.4	29.6	29.4	29.6	31.6	32.0	(b)
Precision	S.D.	6.42	10.1	6.00	6.96	6.19	5.04	
Speed of Arm	$\bar{x}$	.278	.268	.260	.272	.267	.262	Seconds
Movement	S.D.	.058	.055	.050	.048	.050	.050	
Multilimb	$\bar{x}$	28.4	25.6	20.2	19.8	25.0	20.8	(c)
Coordination	S.D.	10.9	8.14	4.87	6.44	7.45	8.63	
Position	$\bar{x}$	17.3	16.1	17.0	17.7	16.8	17.2	Points
Reproduction	S.D.	3.09	2.72	3.59	3.30	2.86	2.21	

(Continued)

Table 3--Continued

Condition / Test		Practice	Practice	Prestress	Prolonged Activity Stress	Prestress	Heat Stress	Units
System Equalization Ability								
Movement	x̄	11.4	12.7	12.4	12.0	10.0	10.8	(c)
Prediction	S.D.	6.28	5.10	4.36	4.30	4.25	4.84	
Rate	x̄	18.5	13.2	11.5	12.1	12.4	12.3	(b)
Control	S.D.	5.83	4.21	2.05	3.15	4.76	2.65	
Perceptual Cognitive Ability								
Perceptual	x̄	60.9	52.5	48.9	48.7	51.0	46.4	Seconds
Speed	S.D.	12.7	7.28	6.93	7.28	8.97	8.94	
Time	x̄	27.3	23.6	22.4	25.3	22.2	25.7	Seconds
Sharing	S.D.	6.72	3.45	2.97	4.76	3.58	5.20	
Reaction Time Ability								
Visual	x̄	.199	.193	.195	.216	.206	.185	Seconds
Reaction Time	S.D.	.041	.021	.021	.029	.026	.038	
Auditory	x̄	.183	.188	.176	.182	.174	.144	Seconds
Reaction Time	S.D.	.036	.026	.026	.032	.031	.033	
Mirror Tracing Ability								
Mirror	x̄	226	148	101	95.6	98.3	87.4	Seconds
Tracing	S.D.	134	70.1	27.7	29.7	39.4	31.9	

a = error score
b = time integral of absolute voltage for x axis
c = error score: absolute value of difference between subject-produced value and calibration value

Examination of the summary table reveals that for some tests performance improved through practice over all six sessions, while other tasks showed either an apparent improvement or decrement under stress relative to performance in adjacent practice trials.

Statistical Analysis

A nonstress "baseline" score was computed for each subject for each test as the mean of his last two practice sessions (3 and 5). These means were then used in the t-test for repeated measures to assess differences between stress and nonstress performance. In computing the t-score, the difference between means was taken in the direction which would produce a negative t-value in the case of performance decrement under stress. This was done for convenience since some tests result in "error" scores or response times which vary inversely with goodness of performance while other tests are scored so that the magnitude of scores varies directly with goodness of performance.

In view of the rather tentative basis on which certain of the experimental results were predicted, a two-tailed test was used to reduce erroneous rejection of the null hypothesis and to leave open the opportunity to discuss statistically significant effects which might occur in the direction opposite to that predicted.

The t-values obtained are shown in Table 4 in order of magnitude from large-positive to large-negative. The scores are so arranged to facilitate reference in subsequent discussion. It is not implied that a rank ordering of t-scores may be used to attribute more or less "significance" to one result or another in the statistical sense. Nor may it be said that a larger "t" is indicative of higher sensitivity to the independent variable as compared with a lower "t" of some other measure.

Table 4

Summary of t-test Analysis Comparing Stress vs Nonstress Performance

Stress Condition			
Heat		Prolonged Activity	
Test	t	Test	t
Auditory RT	6.510*	Arm-hand Steadiness	2.766*
Response Orientation	5.161*	Multilimb Coordination	2.353*
Mirror Tracing	3.451*	Perceptual Speed	1.349
Perceptual Speed	2.954*	Mirror Tracing	1.157
Visual RT	2.262*	Control Precision	1.005
Wrist-finger Speed	2.199*	Position Reproduction	0.850
Manual Dexterity	1.987	Finger Dexterity	0.830
Finger Dexterity	1.701	Rate Control	0.704
Position Reproduction	1.030	Wrist-finger Speed	0.487
Arm-hand Steadiness	0.986	Response Orientation	0.487
Multilimb Coordination	0.911	Position Estimation	0.000
Movement Prediction	0.649	Speed of Arm Movement	-0.476
Rate Control	0.461	Auditory RT	-0.7633
Speed of Arm Movement	0.369	Movement Prediction	-1.006
Control Precision	-1.821	Manual Dexterity	-1.256
Position Estimation	-2.424*	Visual RT	-1.559
Time Sharing	-2.586*	Time Sharing	-2.847*

*$p < .05$

$t_{.05,\ df = 17} = 2.110$

Note: Positive t-score indicates performance facilitation. Negative score indicates decrement.

Physiological Measures

Oral temperature, pulse rate, and blood pressure were measured at the beginning of each testing session and at two-hour intervals thereafter. Records of individual subjects were examined for any marked deviation from expected values which might indicate an "abnormal" reaction to heat or work/rest stress. No evidence of such reaction was found. Upon initial inspection of these data, it was found that the measures obtained at two-hour intervals throughout the 24-hour work/rest period showed only typical diurnal variations. For this reason, only the initial and terminal measures for that condition are presented.

Means and standard deviations of temperature, pulse rate, and blood pressure based on the 18 subjects are shown for the various test conditions in Table 5.

Heat Stress

Exposure to high ambient temperature produced a steady increase in group mean temperature from 98.3° F immediately preceding heat stress to 101.2° F at the end of six hours. During the same period, mean pulse rate increased from 78 beats/min to 111 beats/min. No appreciable change was observed in either systolic or diastolic blood pressure.

Prolonged Activity

The work/rest schedule had no marked effect on temperature, pulse rate, or blood pressure. As may be seen in Table 5, the mean values obtained at the end of the work/rest session were essentially the same as at the beginning of the session.

Table 5

Means and Standard Deviations of Physiological Measures

		SESSION							
		Practice		Prolonged Activity		Time in Heat (hrs)			
Measure		1	2	Initial	Terminal	0	2	4	6
Oral Temperature (^{o}F)	$\bar{x}$	98.6	98.4	98.4	98.2	98.3	98.8	99.5	101.2
	SD	0.45	0.28	0.10	0.45	0.52	0.46	0.50	0.77
Pulse Rate (beats/min)	$\bar{x}$	79	76	77	75	78	85	105	111
	SD	10	11	10	9	8	9	14	15
Blood Pressure Systolic	$\bar{x}$	123	124	121	126	120	119	119	120
	SD	17	18	17	22	19	18	19	19
Diastolic	$\bar{x}$	78	75	75	81	77	79	77	76
	SD	10	9	12	15	14	11	9	9

DISCUSSION

A principal objective of this study was to determine the differential sensitivity of a number of relatively independent measures of perceptual-motor performance to two types of stress likely to be encountered within the aerospace environment. Of interest was the extent to which different primary dimensions of perceptual-motor performance would be affected under conditions of high ambient temperature and under conditions of prolonged activity. Performance was measured using an integrated measurement system capable of providing scores on 18 basic dimensions of perceptual-motor performance. A second purpose of this study was to determine the usefulness of this measurement system as a research device for the study of human performance.

An implicit assumption in this investigation was that different dimensions of performance would be affected unequally by the same stress condition. To the extent that meaningful measures can be obtained of such changes in the basic dimensions of performance, one will gain insight into the manner in which more complex performance varies under stress. Ultimately, through an understanding of the dimensional structure of complex activities such as those involved in the dynamic control of spacecraft, one should be able to predict with reasonable certainty the extent to which control capability will be degraded under different environmental conditions.

Performance versus Physiological Functioning

A question of concern was the extent to which stress induced performance changes might be associated with variations in physiological functioning. Rather than attempting to correlate each perceptual-motor performance dimension with pulse rate, temperature, or blood pressure, it was considered preferable for present purposes to view the physiological data as an indication of the general, and changing, state of the organism during the period of performance. In this manner, specific changes in performance could be associated with the overall operating effectiveness of the subject rather than with the separate physiological parameters. In any event, a positive or negative correlation between performance on a given task and, say, pulse rate or temperature would still require use of more general explanatory concepts as to how or why such a relationship might exist.

Predictions concerning the effect of heat stress and prolonged activity on perceptual-motor performance were made within the context of arousal theory. Under these terms, the human operates at what for him is a normal level of arousal, on a continuum which can vary from sleep to complete panic. A limited application of heat should increase the level of arousal while prolonged activity should operate to decrease this level. In examining the physiological data, therefore, the basic question was whether these data supported the anticipated levels of arousal.

The heat stress data, i.e., mean oral temperature of 101.2° F and pulse rate of 111 beats/min, may be interpreted to indicate an above-normal level of arousal. The lack of change in blood pressure may be ascribed to vasodilation of arterioles as cutaneous circulation is increased in response to the heat (Brobeck, 1965). However, even though no change is noted in blood pressure, the increased pulse rate is an effective indicator of the heightened autonomic nervous system activity which serves to increase arousal level.

In other research concerned with the physiological correlates of arousal, blood pressure has been found to differentiate significantly between high and low arousal conditions (Schnore, 1959). However, in this investigation, the heightened arousal was produced by threat of shock and by intense auditory distraction. Heat was not a stimulus, and thus heat-induced peripheral vasodilation did not negate the normal increase in blood pressure. A comparison of the investigation of Schnore with the present study clearly shows how the effect of individual physiological parameters must be interpreted in the light of the specific environment and task conditions which are used.

The physiological parameters measured at the end of the prolonged activity session were essentially the same as at the start of the session with no appreciable variations observed during the intervening period. It is apparent that for healthy young subjects such as those in this investigation a 24-hour period of extended activity does not produce fatigue effects which are reflected by changes in peripheral physiological measures. This, of course, does not rule out the occurrence of significant changes in performance during this period, since the performance measures might well be more sensitive to small changes in the state of the subject than are the physiological indices. However, this does rule out the use of this type of physiological measure as an indication of performance change under this stress condition.

Stress Effects

Heat Stress

Facilitative Effects. Under conditions of heat stress, performance facilitation was observed in six measures. These were:

Auditory Reaction Time
Response Orientation
Mirror Tracing
Perceptual Speed
Visual Reaction Time
Wrist-Finger Speed

Tasks expected to benefit from the alerting component of arousal are those with distinctive and discrete information inputs requiring little mental encoding, decoding, or translation, and involving simple motor reactions. Four of the above measures (Visual and Auditory Reaction Time, Wrist-Finger Speed, Response Orientation) appear to meet these criteria. Improvement in these abilities under heat conditions is consistent with arousal theory.

The improvement shown in Perceptual Speed and Mirror Tracing does not conform as readily to the tenets of arousal theory. However, it may be that increased arousal is accompanied by increased attention to small detail.

Degrading Effects. The following measures showed performance degradation under heat stress:

Time Sharing
Position Estimation

It is expected that tasks involving some amount of information acquisition and processing will suffer due to competition from stress stimuli. Inasmuch as the test battery focuses on perceptual-motor performance, task information loading and cognitive requirements are relatively low. However, one may distinguish among the tasks to some extent on this dimension. For example, there is a difference between the very simple stimulus for the Reaction Time tasks and the more complex meter comparisons which serve as the stimulus for the test of Perceptual Speed.

Both the Time Sharing task and the Position Estimation task are fairly complicated by comparison with many of the other tasks. Each requires a high level of attention to the task for successful completion. It is this component of performance which appears most susceptible to the competing effects of the stress stimuli.

Prolonged Activity

Performance Facilitation. Performance on two tasks showed improvement at the conclusion of the 24-hour period of prolonged activity. These were:

Arm-Hand Steadiness
Multilimb Coordination

No tasks were expected to show improvement following prolonged activity. There would appear to be no evidence in the literature on work-rest cycles, sleep deprivation, or fatigue which would indicate that this stress condition should result in improved performance over that found with well-rested subjects. At best, one might expect performance to be maintained at its prestress level. The improvement found with these two tasks was not expected.

A reasonable hypothesis for the improvement in Arm-Hand Steadiness can be advanced if one accepts a somewhat lower level of arousal at the end of 24 hours even though the physiological indices show no change. Under these conditions, there would be a lowered muscle tension in the arm and hand and consequently a reduced level of tremor. If this is true, slight fatigue operates to improve limb steadiness rather than to reduce it.

Reasons for improved Multilimb Coordination are less obvious. One possibility may be that in performing a two-hand rate control tracking task of the type used in this study, it is common for subjects to introduce error into the system which they must then eliminate above and beyond the forcing function provided in the system. Skilled trackers, on the other hand, will make control inputs which simply cancel the forcing function. There is, in other words, a tendency for naive subjects to overcontrol the system until considerable facility is developed.

Consequently, early tracking performance scores are often poorer than they would be if the subject kept his hands off of the controls entirely (assuming, for example, that something like a simple sinusoidal forcing function were used).

In the present tracking task, sine wave forcing functions are used in both axes. The maximum score which can be registered is 50 (arbitrary units), the capacity of the scoring integrators. Such a score represents quite poor performance. The very best scores which have been produced on this device by skilled trackers other than the experimental subjects are in the order of 7-9 units. Scores for the present subjects averaged about 20 units. Thus, while the subjects performed reasonably well, there was still room for substantial improvement. If lowered arousal or fatigue tended to reduce the frequency and magnitude of attempted control movements, thereby reducing operator-induced error, an apparent improvement in tracking performance could result. In view of this possibility, any conclusion implying that prolonged activity stress improves Multilimb Coordination performance must be held open to question.

Performance Degradation. Only the Time Sharing Task showed a significant decrement in performance during the period of prolonged activity. This was rather surprising inasmuch as one would expect this type of stress to reduce performance effectiveness in most, if not all, of the tasks. These results suggest that 24 hours of relatively continuous activity does not represent either a psychological or physiological burden to young, healthy, motivated subjects and that they are able to maintain consistent levels of performance throughout the period of activity. The fact that the Time Sharing task deteriorates may be attributed again to the high attention requirement of this task and its susceptibility to competition from the stress stimuli.

Relative Sensitivity of Tests to Stress

It was found that within each stress condition certain performance measures were degraded, others improved, and some remained essentially unchanged. Since the stress levels employed were not particularly intense, one may assume that these stress conditions were above threshold for certain tasks and below threshold for others. If stress intensities were increased, one might obtain considerably different results. Certainly, if ambient temperature were raised to extreme levels, or if subjects were exercised to the point of complete exhaustion, all measures of performance would show change. However, it was not the intent of this study to conduct a comprehensive scaling of stress effects with respect to the 18 measures of perceptual-motor performance. This study was more in the nature of an exploratory investigation, designed primarily to validate the usefulness of the performance measurement system as a research device for the study of selected stress effects upon performance. However, the stress intensities which were used represent levels which might reasonably be expected during aerospace operations and are at about the level at which one might begin to be concerned over possible effects on performance capabilities.

In attempting to assess the relative sensitivity of the various performance measures to stress, consideration must be given to the extent to which specific tasks may be assumed to represent all performance falling within a particular ability category. Thus one may ask whether "time sharing" performance in the general sense is adequately represented by the Time Sharing task provided by the testing console. The same question applies to the other tasks as well.

Poulton (1965) summarizes clearly the logic involved in drawing conclusions from data of the present type:

> Having selected (two) tasks to represent more general functions or abilities and then subjected these to some independent variable such as environmental stress, four outcomes are possible: (1) no change is found under stress for either task, (2) one task is affected while the other is not, (3) both tasks are affected in the same direction but one to a greater extent than the second, (4) both tasks are affected but in opposite directions. [He states further that] uncertainty is inherent in the first three outcomes since in (1) "no change" may be due either to no effect of the independent variable on the functions or because the tasks selected to represent the functions are insufficiently sensitive. Similarly for (2) and (3) since what may be reflected is the relative sensitivity of the tasks selected to represent the functions rather than a differential effect on the functions themselves.
>
> Legitimate inferences contrasting the effects of an independent variable on two psychological functions can, however, be made when the task representing the other function shows a reliable decrement in the presence of the independent variable.

The extent to which the foregoing restrictions hold would appear to depend in large measure upon the manner in which the representative tasks are selected and/or implemented. In this regard, the present test battery seems to meet the requirements for allowing a degree of generalization from its specific tasks to other types of behavior falling within the general ability categories, since all tests were selected on the basis of the highest factor loadings for a given ability category as determined in a number of laboratory investigations. Accordingly, these tests represent a systematic and scientific approach to the measurement of performance within a given ability category. Therefore, there would appear to be some justification for making at least tentative inferences concerning the relative sensitivity of these measures to the stress conditions used in the experiment, and for interpreting these findings in terms of the ability categories which each test is designed to represent.

Recommendations for Future Research

The realization of a perceptual-motor performance test battery represents a substantial step forward in the capability to assess human performance at a basic level in a wide range of task/environmental situations. Further it provides a much needed complement to the extensive research (Wing & Touchstone, 1963; 1965; Wing, 1965) which has emphasized the cognitive and higher level components of behavior in the aerospace environment. In this regard it would appear that future research would be well directed along two lines.

First, there exists the need to extend information concerning primary human perceptual-motor performance within normal and hostile environments. Little is known, for example, of the effects of hyper- and hypobaric environments, various synthetic atmospheres either in use or anticipated, thermal stress, unusual work/rest schedules, weightlessness, and restricted physical activity on the basic dimensions of human perceptual-motor performance. Even less is known concerning the combined effects of these variables.

Second, recognizing that the study of performance in terms of its various components, i.e., "mental abilities," problem solving, decision-making, motor performance, is both necessary and valuable, there is the further requirement to synthesize the findings of the separate areas if one is to understand and predict performance in real world situations. Few investigators would maintain that the separate effects are simply additive. Thus there is the need for research which deals with various types of performance and stress conditions sequentially and concomitantly.

At the present time it is difficult to say, for example, just what changes might occur in the complex perceptual-motor performance required in the control of a space vehicle when such control occurs under increased acceleration forces, unusual luminance levels, and in conjunction with high information processing requirements. Although a number of investigators have studied the effect of information loading on motor performance (Bahrick, Noble, & Fitts, 1954; Conrad, 1955; Garvey & Henson, 1958; and Williams, 1963), while others have studied the interaction of concurrent cognitive activities and motor performance (Brown, Galloway, & San Guiliano, 1965; Dowling, 1965; Glucksberg, 1963), much work remains before findings of these and other investigations can be tied in with the effects of the many additional stresses of the operational world. If present and future needs of system designers concerning human performance capabilities are to be met, a fund of information must be developed which will permit generalization to a wide range of tasks and operating environments.

Advantages of Use of Test Battery

A clear advantage to use of a test battery which samples a wide range of abilities and task configurations is apparent from the present results where both performance facilitation and degradation were observed for different tests under both stress conditions. This finding emphasizes the rather selective influence of stressors on specific dimensions of human performance. A further benefit to be derived from use of a test battery, as opposed to a single laboratory task (such as the typical time sharing and tracking setups), is that it permits separate assessment of many of the components of the more complex tasks measured in temporal proximity.

Further, there appears to be a clear requirement to deal with the relationship between stress and performance as an interaction (Williams, 1963; Wilkinson, 1963; 1964). It would appear that definitive results within the area of research on stress will not be forthcoming until appropriate steps are taken to measure and control such elusive psychological factors as motivation, level of arousal, perceived relevance of performance to stress reduction, etc., and to determine the manner in which these factors conjointly influence each of the basic dimensions of performance. An integrated test battery capable of providing measures of these basic dimensions should prove to be a valuable item of research equipment in investigations of this nature.

SUMMARY

This study was concerned with the improvement of equipment for the measurement of the basic dimensions of perceptual-motor performance and with an assessment of the effects of two stress conditions on this class of performance. The following are the major findings of this study:

Equipment Redesign

An integrated measurement console, built under a previous program (NASA Contract NAS 9-2542), was redesigned to increase reliability of operation and to improve maintainability. In using this equipment in the study of stress effects, no malfunctions occurred and only minor adjustments were required. The redesign objectives appear to have been met. Details of this redesign effort are presented in an accompanying report (Reilly & Parker, 1967).

Stress Effects

Eighteen subjects were tested under conditions of heat stress (100°F dry bulb, 80°F wet bulb temperatures for a period of six hours) and work/rest stress (24-hour continuous activity with two 2-hour rest periods). While these stress conditions are by no means severe for healthy subjects, it was felt they would be adequate to obtain certain information concerning the relative effects of such stressors on a number of independent dimensions of perceptual-motor performance. It was found that perceptual-motor performance levels are well maintained under these stress conditions. It would appear that considerably higher stress levels must be used if marked deterioration of performance is to be observed. Even at these levels, however, there was indication of differential sensitivity of the items of the test battery to these stresses.

The extent to which these stress conditions interfere with performance appears to depend in large measure upon the characteristics of the task and the specific stimulus environment provided by the stress agent. Both facilitation and degradation of performance were observed for different tasks within each stress condition, suggesting a task by stress interaction effect. The following specific stress effects were noted:

Effects of Heat

Table 6 lists those tasks which showed a significant change during the period of increased ambient temperature.

Table 6

Tests Showing Significant Change
Under Heat Stress

Facilitation	Degradation
Auditory Reaction Time	Time Sharing
Response Orientation	Position Estimation
Mirror Tracing	
Perceptual Speed	
Visual Reaction Time	
Wrist-Finger Speed	

Tests showing improvement under heat stress can be accounted for in terms of arousal theory under which activities with distinctive and discrete information inputs requiring little mental encoding, decoding, or translation, and involving simple motor reactions, can be expected to benefit from the alerting component of arousal. The deterioration of the Time Sharing and Position Estimation tasks may be a function of the high attention requirements of these activities and the consequent susceptibility to the distracting influence of the heat environment.

Oral temperature and pulse rate increased significantly during heat stress and thus lend support to the inference of increased arousal during heat exposure and the concomitant facilitation of performance on certain tasks. Blood pressure did not change during heat exposure, presumably due to vasodilation of arterioles.

Effects of Prolonged Activity

Table 7 lists those tasks for which a significant change was noted under the 24-hour period of prolonged activity.

Table 7

Tests Showing Significant Change
Under Prolonged Activity

Facilitation	Degradation
Arm-Hand Steadiness	Time Sharing
Multilimb Coordination	

While no task performance was expected to improve during the prolonged activity condition, two did, in fact, show significant improvement. Facilitation of Arm-Hand Steadiness may be accounted for on the basis of arousal theory in that reduced muscle tension following sleep loss would result in lessened limb tremor. Improved Multilimb Coordination performance, however, is viewed as a fortuitous reduction in tracking error resulting from reduced operator control inputs, which in turn tend to decrease the amount of operator-induced error in the tracking system. The deterioration in Time Sharing performance may be a function of the high attention requirements of this task and consequent susceptibility to even minimal fatigue.

Oral temperature, pulse rate, and blood pressure showed no change during the period of prolonged activity. This, plus the finding that only one performance measure was degraded by this work schedule, is consistent with the well-known fact that human operators can tolerate considerable amounts of stress, whether task-induced or environmental, before there is an obvious and extensive impairment of perceptual-motor or physiological functioning (Bass, 1963; Adams & Chiles, 1963).

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APPENDIX A

SCHEDULE OF SUBJECT ACTIVITIES DURING HEAT STRESS

Activity	Subject Performance Requirements	Time
	--Normal Temperature--	
Console Testing	Perform on 18 console tests.	0800-0930
	--Begin Heat Stress--	
Unusual Uses Test	Given a list of common objects, e.g., brick, safety pin, generate as many uses as possible for the objects other than those for which they were intended. For example: safety pin--fish hook. Five objects--ten minutes per object.	0930-1020
Conversion Arithmetic	Use alphabet-number chart to convert arithmetic problems from letters to numbers, then solve problem mentally and write down answer. For example, subject sees A + F + M = ___ on worksheet. From his chart, he substitutes the corresponding numbers and solves: 6 + 10 + 12 = 28.	1020-1120
Word Analysis	Construct as many words as possible from the letters contained in a large word provided. For example: consolidate--date, slit, idol, load, etc. Ten base words. One-hour time limit.	1120-1200
Lunch	(Subject remains in heat.)	1200-1220

Activity	Subject Performance Requirements	Time
Word Analysis	Continues with task as shown above.	1220-1300
Attention to Detail	Given list of nonsense words, subject notes whenever any letter appears more than once within a word and tallies number of times letter occurs. Fifteen hundred items. One-hour time limit.	1300-1400
Console Testing	Perform on 18 console tests.	1400-1530

--End of Heat Stress--

APPENDIX B

SUBJECT WORK SCHEDULE DURING PROLONGED ACTIVITY STRESS

Activity	Subject Performance Requirements	Time
Console Testing	Perform on 18 console tests.	0800-1000
Minnesota Multiphasic Personality Inventory	IBM answer sheet.	1000-1100
Edwards Personal Preference Inventory	Standard test form.	1100-1200
Lunch	Subject allowed to eat lunch; could stand or sit; reclining not permitted.	1200-1230
Vigilance	Subject monitors stimulus light which appears at random intervals; responds by pressing button. Score is cumulative response time to detect 48 signals.	1230-1300
Word Detection	Listen to tape recorded messages to detect the frequency of occurrence of a pre-selected key word. "Messages" are articles from scientific magazines and basic textbooks.	1300-1400
Binary Decision-making	Predict which of two lights will appear; bet from one to five points on each trial for a total of 140 trials. Attempt to develop winning strategy during course of test. (Stimulus sequence was actually random, with equal probability of occurrence for each of the two events.)	1400-1530

Activity	Subject Performance Requirements	Time
Decoding Proverbs	Use a code card in which letters of the alphabet correspond to numbers. Substitute letters for numbers in a series of 30 numerically coded proverbs.	1530-1700
Dinner and Rest Period	Subject could sit or stand; reclining not permitted.	1700-1900
Digit Span	Listen to tape recorded sequences of digits. Write the digits in order on answer sheet after hearing complete sequence. Sequences began with five digits and were increased by one digit to a maximum of ten digits.	1900-1920
Decoding and Visual Search	Use code card in which letters of the alphabet correspond to numbers. Decipher 21 numerically encoded map locations. Find and mark each location on map provided.	1920-2050
Object Count	Count the total number (1,000) of small nuts, bolts, and washers in a container.	2050-2100
Vigilance	(Same as Vigilance above.)	2100-2130
Mental Arithmetic	Solve set of 40 addition, subtraction, multiplication, and division problems presented by tape recorder without doing any calculations on paper.	2130-2230
Solid Puzzles	Disassemble and reassemble complex, three-dimensional wooden puzzles.	2230-2400
Time Interval Estimation	Estimate set of predetermined time intervals ranging from ten seconds to fifteen minutes by starting timer (hidden from view), waiting and then stopping timer when prescribed interval is judged to elapse.	2400-0100

Activity	Subject Performance Requirements	Time
Rest Period	Subject permitted to rest on cot.	0100-0300
Card Sorting	Shuffle standard deck of playing cards and sort into suits as rapidly as possible (five trials). Shuffle deck and sort into four categories as follows: (1) all odd-numbered black cards, (2) all even-numbered black cards, (3) all odd-numbered red cards, (4) all even-numbered red cards (five trials).	0300-0315
Vigilance	(Same as Vigilance above.)	0315-0345
Object Sort	Sort total of 1,000 nuts, bolts, and washers into three-partition container.	0345-0400
Geometric Puzzles	Arrange a set of cardboard squares, rectangles, and triangles to form larger geometric figures outlined to scale on worksheets.	0400-0500
Mechanical Disassembly/Assembly	Use screwdriver to disassemble and reassemble a complex object constructed of small, flat pieces of sheet metal held together with washers, nuts, and bolts.	0500-0530
Visual Search	Find a series of locations on map and mark positions.	0530-0630
Console Testing	Perform on 18 console tests.	0630-0800

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